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Research Article

# Possible effects of shipping routes on coral reef degradation and diversity in Karimunjawa Marine National Park, Java Sea

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## Abstract

The Karimunjawa Marine National Park, situated in the Java Sea, Indonesia, is renowned for its rich biodiversity and lively coral reefs. However, amidst the backdrop of this natural beauty, concerns have been raised regarding the potential impacts of shipping activities on the health and diversity of these fragile ecosystems. The increase in maritime traffic, including commercial vessels, tourist boats, and fishing vessels, traversing through the Karimunjawa Marine National Park, raises significant environmental concerns. The movement of these vessels, especially along specific shipping routes, has the potential to disturb and damage coral reefs through various mechanisms. Hence, this study aimed to investigate the possible impacts of shipping routes on the coral abundance and diversity and the coral health in the Karimunjawa Islands, Java Sea, Indonesia.

This study categorized ship routes into West Route, East Route, and Non-Route and assessed coral health and diversity across 15 islands. Key metrics analyzed included coral disease prevalence, coral cover, diversity index, species richness, relative abundance, and evenness, using 15 × 2 m belt transects at 3 and 8 m depths with three repetitions each.

Statistical analysis revealed significant differences in coral abundance and species richness among ship-route groups, but no significant depth-related differences. These results suggest that while shipping routes affect certain aspects of coral health and diversity, other factors may be more influential in shaping coral disease prevalence and overall diversity in Karimunjawa reefs.

**Key words:** Biodiversity, coral reefs, degradation, Karimunjawa, shipping route

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## Introduction

More than fifty thousand ships move around the world every year, lugging millions of containers (Sinay 2022). As global trade continues to expand, maritime shipping is poised for rapid growth. The primary shipping routes are expected to experience heightened congestion and a potentially unprecedented increase in traffic in the coming years (IMO 2019). As a result, all stakeholders in the maritime sector explore more effective methods for managing ships, trade routes, transit times, cargo ports, and containers (Lind et al. 2016).

In the context of environmental concerns, cruise ships are frequently observed discharging substantial amounts of sewage, food waste, and oily bilge water, containing insoluble particles, into the ocean. Byrnes and Dunn (2020) reported addressing pollution discharge from cruise ships and highlighted that the decomposition of these wastes and ocean dumping contributes to water acidification and a significant reduction in oxygen levels. This, in turn, leads to the proliferation of toxic algae blooms, posing a substantial threat to coral reefs (Lloret et al. 2021). Additionally, with the cruise industry's shift towards increasingly larger ships, tourist destinations face the challenge of adapting to the latest generation of ships. These ships require deeper and wider shipping lanes, which presents a dilemma for many tourist destinations. The location of shipping lanes close to shore, through which cruise ships pass, has significant environmental and economic impacts. Larger tract dredging can damage habitat, while ship traffic can result in sediment buildup that has the potential to cover sensitive habitats such as coral reefs and seagrass beds. Additionally, dredging costs tend to vary spatially (Sinay 2022).

Coral reefs are one of the seabed ecosystems that are very beneficial for human life because of their enchanting aesthetic beauty as a recreation area, their ecological function as a coastal barrier from waves and erosion, and because they are a fish habitat for spawning, rearing, and fishing grounds for various types of fish and other marine organisms, as well as providing active compounds for various pharmaceutical and medicinal purposes (Hoegh-Guldberg 2011; Gracia et al. 2018; Reguero et al. 2018; Zhao et al. 2019).

Shipping routes are the navigating lanes, both natural and man-made, in wide waterways used by large vessels to connect major ports and carry cargo (Pirotta et al. 2019; Sinay 2022). These routes allow efficient, safe, and economical transportation of goods while offering the shortest sailing times. Karimunjawa Marine National Park (KMNP) which is composed of 27 islands is one of seven marine national parks in Indonesia. This archipelago is located about 100 km north of Semarang, Central Java. The richness of coral and coral fish species in Karimunjawa consists of about 100 species of corals documented from more than 50 genera and approximately 250 species of fish (Edinger et al. 2000). Consequently, tourism in KMNP has increased remarkably over the last decade. Since the early 2010s, cruise ship travel has experienced nearly continuous growth, exceeding 25% annually (Sabdono 2019b). Associated with the increasing tourism boom has been an increase in the total number of cruise ships and the routes of ship traffic (Sabdono et al. 2019a). This situation in the vicinity of coral reefs is not always benevolent and corals are subject to continuous stress. The negative impacts can include coral degradation and loss of marine life.

The increasing volume of ship traffic, water pollution from ships, and increased direct physical pressure on coral reefs due to ship groundings and anchoring activities are factors that allow damage to coral reefs (Walker et al. 2019; Zhang et al. 2019; Kostianaia et al. 2020; Satya et al. 2023). Today, the study on the impact of increasing shipping routes on the existence and health of coral reefs is limited. Few previous studies reported that damage to coral reef ecosystems has long-term impacts that cause reduced marine biodiversity, decreased fish populations, and loss of habitat for marine organisms (Veron

et al. 2009; Eddy et al. 2021). Increasing human activity around KMNP due to the ever more crowded shipping traffic traversed by commercial ships, tourist ships, and local transport has become an important part of the economic life of the community and the environment in Karimunjawa. This is because the impact of increasing shipping routes on the existence and health of coral reefs is not yet fully understood. Hence in this study, the possible effects of shipping routes on coral reef degradation and diversity were investigated.

## Materials and methods

### Study area

The study area encompasses Karimunjawa Marine National Park, located in the Java Sea, Indonesia. The park comprises a group of 27 islands and surrounding marine areas, renowned for its diverse marine ecosystems including coral reefs, seagrass beds, and mangroves. Based on the tourism destinations and geographic locations, the ship routes were grouped into 3 categories (west, east, and non-routes). The West Route refers to regular arrival in those islands that are situated in the western part of Karimun island including Menjangan Kecil, Burung, Geleang, Cemara Besar, and Cemara Kecil islands. The East Route refers to regular arrival in those islands that are situated in the western part of Karimun island including Menjangan Besar, Gosong Saloka, Kecil, Tengah, and Sintok islands. Non-route refers to irregular arrivals of tourism in those islands including Sambangan, Seruni, Genting, Cendekia, and Menyawakan islands (Fig. 1).

### Line Intercept Transects (LIT) and Belt transect

Three belt transects, with 2 × 15 meters (30 $m^2$) in size, were randomly established on each of the 15 islands. These transects were located at depths of 3 meters and 8 meters. The LIT *in situ* was established in the middle of the belt transect. Hence the total number of LIT and belt transects established is 90 transects. Divers identified all benthic categories and estimated the percent hard coral cover (scleractinian corals) by dividing the total length of occurrence of hard corals by the total length of the transect. Within each belt transect, all scleractinian coral colonies exceeding 5 centimeters in diameter were recorded based on their genus. Corals were further classified as either healthy or diseased (Figs 4, 5).

### Health and diseased corals

Diseased colonies exhibited manifestations such as changes in color or structure, tissue loss, necrosis, and abnormal growth. Conversely, healthy colonies displayed no signs of lesions or other indications of compromised health. The prevalence of coral diseases was determined for each belt transect by dividing the number of colonies showing signs of each disease by the total number of colonies present in each transect. The other variables measured for reef degradation were % coral cover, H-index (H'), species richness (SR), and evenness (E).

**Figure 1.** Route ships of Karimunjawa (Note- red: east shipping route; green: west shipping route; blue: non-route).

## Data analyses

Parameters observed included coral damage, underwater photography, oceanographic parameters, type and number of corals per transect, number (healthy/sick coral), and percent coral cover. To determine the prevalence and coral cover, the formula used was adopted from Raymundo et al. 2008)):

$$Percent\ Prevalence = \frac{\sum Diseased\ coral\ colonies}{\sum Total\ colonies} \times 100 \quad (1)$$

$$Percent\ Coverage = \frac{Life form\ coverage\ length}{\sum Total\ transect\ length} \times 100 \quad (2)$$

The Shannon-Weaver index was used to measure the H', GR, and E of coral reefs: $H' = \sum_{i=1}^{S} Pi\ lnPi$ (3); $E = H'/lnS$ (4)
where: *pi* = relative abundance, S = species richness; H'= diversity index, and E-evenness.

Analyses of Variance-one way were used to explore the impact of shipping routes on disease prevalence, coral cover, and biological diversity of corals among islands by using SPSS-22 software.

# Results

## Impact of shipping-route traffic on the prevalence of coral diseases

The mean prevalences of coral disease in the west, east, and non-route are 7.5, 5.8, and 5.2 percent, respectively (Fig. 2). Statistically, there was no significant difference among routes in prevalence. White Syndrome (WS), White Blotch

**Figure 2.** Coral diseases prevalence of Karimunjawa on three shipping routes (Note: the same word characters means no significant differences)

(WB), Black Band Disease (BBD), Pigmentation Response (PR), White Plague (WP), Ulcerative White Spot (UWS), Black Disease (BD), Growth Anomaly (GA) and Skeleton Erode (SE) were detected in all routes (Fig. 3).

## Impact of shipping-line activity on % coral cover

Fig. 4 demonstrated that the % coral cover in the west, east, and non-cruise lines were 68.14, 64.9, and 61.18 percent, respectively. Statistically, there was no significant difference among routes in % coral cover.

## Impact of shipping-route activity on abundance and diversity

Statistical analysis showed that the impact of shipping-line activity on coral abundance and species richness is significantly different (Table 1, Fig. 6.). However, there are no significant differences in terms of diversity and evenness. Post-hoc test $LSD_{5\%}$ revealed that the coral abundance and species richness on the west route were significantly different to the east route, and no significant difference to the non-shipping route.

## Depth effect on the prevalence of coral diseases, % coral cover, abundance, and diversity

The effect of shipping-route activity in response to increases in depth, specifically, whether relationships exist between depth and prevalence of coral diseases, coral cover, and diversity was presented in Table 2.

**Table 1.** The effect of shipping route on the Diversity, Abundance, Species Richness, and Evenness of corals.

| Shipping route | Diversity (H') | Relative Abundance (RA) | Species Richness (SR) | Evenness (E) |
|---|---|---|---|---|
| West route | 2.18 ± 0.7[a] | 36.6% [a] | 17.86 ± 0.65[a] | 0.76 ± 0.02[a] |
| East route | 2.02 ± 0.9[a] | 26.5% [b] | 14.04 ± 1.01[b] | 0.78 ± 0.02[a] |
| Non-route | 2.2- ± 0.8[a] | 37.0% [a] | 17.12 ± 0.61[a] | 0.79 ± 0.01[a] |

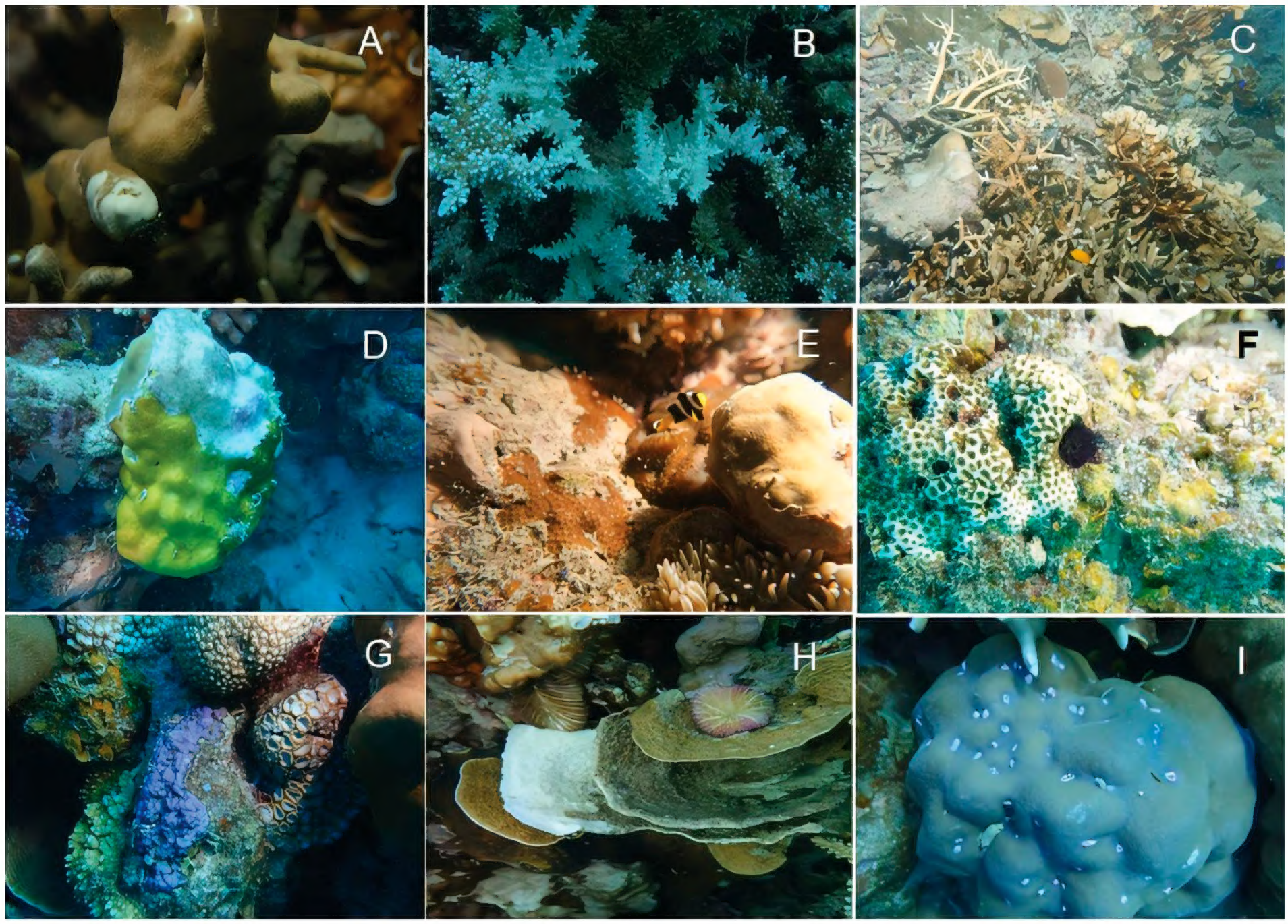


**Figure 3.** Coral diseases prevalence of Karimunjawa [Note: **A** White Blotch (WB) **B** White Syndrome (WS) **C** Sedimental Eroding (SE) **D** White Plague (WP) **E** Skeletal Erode (SE) **F** Bleaching Syndrome (BS) **G** Growth Anomaly (GA), **H** Black Band Disease (BBD), and **I** Pigmentation Response (PR)].

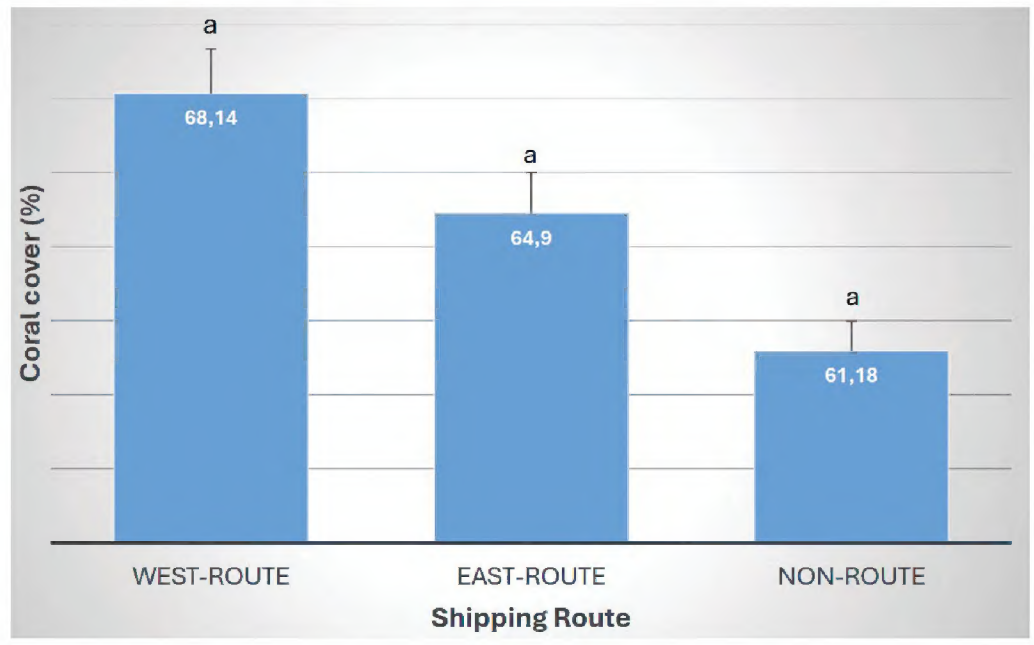


**Figure 4.** Percent coral cover of line-transect on shipping route.

**Table 2.** The effects of shipping-route activity on the prevalence of coral diseases, % coral cover, and abundance and diversity on different depths.

| No. | Depth | Prevalence (%) | Coral Cover (%) | H-Index | Species Richness | Evenness |
|---|---|---|---|---|---|---|
| 1. | 3 m | 6.18 ± .94 a | 67.07 ± 2.42 a | 2.15 ± .06 a | 16.22 ± .59 a | .79 ± .01 a |
| 2. | 8 m | 6.43 ± .73 a | 62.85 ± 2.89 a | 2.13 ± .04 a | 17.07 ± .72 a | .76 ± .01 a |

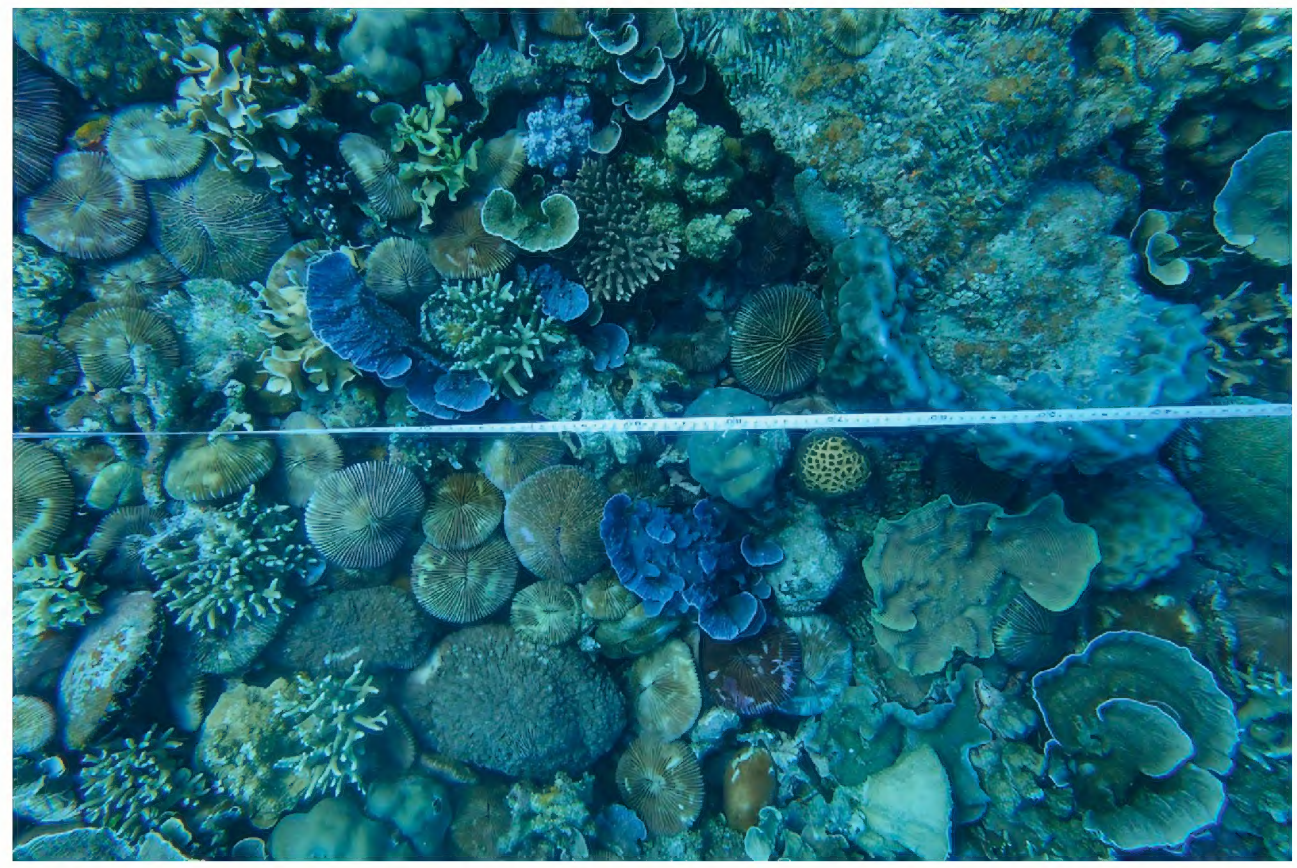

**Figure 5.** Line intercept transect (LIT).

**Figure 6.** Impact of shipping-line activity on abundance and diversity.

## Discussion

The prevalence rate of the disease is the proportion of the coral population with that disease at a point in time. It indicates how many of the corals are sick. Fig. 2 showed that statistically there was no significant difference among routes in prevalence, even though there were 9 different coral diseases detected on each shipping route. It indicates a widespread issue affecting coral reefs in these areas. The prevalence of coral disease in the west of the shipping route tends to be high and the non-cruise lines are the lowest one. Some previous studies of Karimunjawa coral diseases reported that coral disease prevalence in Menjangan Besar ranged between 10.6 and 43.61% and found BBD, BrBD, UWP, WS, YBD, PR, WP, and WBD (Nursalim et al. 2022). A swift evaluation of coral disease across three islands—Genting, Seruni, and Sambangan in the Karimunjawa revealed that human activities, specifically coastal settlement, and floating cage mariculture, were responsible for the onset of coral disease. However, there

was no notable difference in coral disease prevalence among areas frequented by the shipping route and those that were not frequented (Sabdono et al. 2019[a]; 2019[b]). Compared to other studies in different regions of Indonesia, such as the coral disease prevalence in Panjang Island (Sabdono et al. 2014), the prevalence of coral diseases in the 15 islands of Karimunjawa in this study is lower.

The discharge of pollution from cruise ships, including decaying waste and ocean dumping, leads to increased acidification of the waters and a significant reduction in oxygen levels. This, in turn, promotes the growth of harmful algae blooms, which pose a serious threat to coral reefs (EPA 2008). Even the shipping route has no significant difference in the percentage of coral cover in this study, however, shipping lines have detrimental effects on coral reef ecosystems in Southeast Florida (Walker et al. 2012). Additionally, the Great Barrier Reefs (GBR) have been changed by human activities, and live coral cover has declined overall (Sweatman et al. 2011). In this study, the west route is the most visited by tourists, vessels, boats, and ships, yet it has the highest percentage of coral cover. Based on the data available, the differences observed in coral cover between the west, east, and non-cruise lines are not significant enough to conclude that one category has significantly more or less coral cover compared to the others. However, through knowing that there were no significant differences between the pathways, environmental management can detail conservation efforts evenly across the region, without focusing too much on one pathway. It is important to continuously monitor and analyze data to support conservation policies and sustainable environmental management. Further research may be needed to understand the factors behind the differences in % coral covers in each pathway.

Table 2 showed that there were no significant differences between depths of 3 m and 8 m in prevalence of coral diseases, % coral cover, abundance, species richness, and diversity. However, the % coral cover tends to decrease with depth, likely due to reduced light. Meanwhile, reduced light exposure at greater depths can constrain the photosynthetic activities of zooxanthellae (Kahng et al. 2019; López-Londoño et al. 2024). Additionally, very low water flow may result in the formation of boundary layers around the coral surface, hindering nutrient absorption and consequently suppressing coral respiration and growth (Nelson and Altieri 2019; Hughes et al. 2020). It is important to note that each location has unique conditions, and human impacts on coral reefs are highly dependent on the local context. In addition, effective conservation and management efforts can help reduce the negative impacts of human activities on coral reefs at various depths.

## Conclusion

In conclusion, the management of the KMNP area is relatively sufficient according to the currently available data, and even though the shipping lanes are quite congested, coral cover is still maintained. The most important result was that between the non-route route and the west route, there were no significant differences in coral abundance and species richness. However, it is necessary to consider again the limited data obtained and the limited research time available, so that it cannot capture long-term trends or changes in coral cover. So, it is necessary to carry out further research to find out the specific causes of differences in coral abundance and species richness in the context of shipping route activities.

# Additional information

## Conflict of interest

The authors have declared that no competing interests exist.

## Ethical statement

No ethical statement was reported.

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## Author contributions

A. Sabdono, conceived and designed the study methodology, analyzed and interpreted the data, drafted the manuscript, visualization, supervision, project administration, and funding acquisition. D.P. Wijayanti, conceived and designed the study methodology, analyzed and interpreted the data, and wrote—reviewed, and edited the manuscript. M. Helmi, analyzed and interpreted the data, writing—reviewing, and editing. E.D. Satya analyzed and interpreted the data, and data curation.

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## Data availability

All of the data that support the findings of this study are available in the main text. The data underpinning the analysis reported in this paper are deposited at “Data repository” at https://doi.org/10.3897/biorisk.xx.xxxxxx.

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## Supplementary material 1

### Coral abundance data

Authors: Agus Sabdono, Diah Permata Wijayanti, Muhammad Hilmi, Eridhani Dharma Satya

Data type: xlsx

Explanation note: Coral abundance of the West Route, East Route, and Non-Route including a total of 15 islands were recorded as raw data to calculate H indexes, evenness and relative abundance.

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Link: https://doi.org/10.3897/biorisk.22.124897.suppl1

## Supplementary material 2

### Coral reef degradation and diversity in Karimunjawa

Authors: Agus Sabdono, Diah Permata Wijayanti, Muhammad Hilmi, Eridhani Dharma Satya

Data type: docx

Explanation note: This data is summary of data analyzed result from coral abundance and coral cover raw data.

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